PATENT

IN THE UNITED STATES PATENT AND TRADE MARK OFFICE

Applicant	: Murray et al	Examiner	: L. Tran
Serial No.	: 10/663437	Group Art Unit	: 1725
Filed	: September 16, 2003	Docket	: U 014758-5
Title	: MAGNESIUM PRESSURE CASTING		

DECLARATION

I, MORRIS TAYLOR MURRAY, of 51 Teal Lane, Briar Hill, Victoria 3088, Australia, declare and say as follows:

1. I am a co-inventor of the subject matter claimed in the above-referenced patent application Serial No. 10/663437, filed September 16, 2003 (hereinafter referred to as "the present application"). I am the same Morris Taylor Murray who on October 18, 2002, made a declaration filed under cover of a communication dated October 24, 2002, filed in respect of parent application 09/554507 (now US patent 6634412), and who on 3 June 2005 made a declaration filed under cover of a communication dated 8 June 2005 filed in respect of the present application. Full details of my academic and professional experience are set out in pages CV/1 to CV/19 of my Curriculum Vitae attached to my declaration made on

18 October 2002 and filed in respect of said parent application 09/554507, as supplemented by my declaration made on 3 June 2005 and filed in respect of the present application. I have carefully read, and I am thoroughly familiar with the office action mailed on 22 August 2005 in respect of the present application and with the disclosure of US patent 5685357 issued to Kato et al.

2. As detailed in my declarations made on 18 October 2002 and 3 June 2005, I have in excess of 30 years of industrial and research experience in the technology of application 10/663437. I am an international expert of high standing in that technology. In just the 30 months following my resignation from the assignee, I have established an internationally successful consultancy business. In that period, I have provided expert advice on in excess of 200 projects and, in providing this service, I have been required to visit many companies throughout Australia, as well as the USA, Germany, Korea, South Africa, Japan, Malaysia, Denmark, Sweden and the UK. I have no business interest in the invention of application 10/633437. Indeed, such interest as I have is based on my role as a co-inventor and professional pride in my involvement in the very significant invention of that application.

3. The reasoning put forward for the rejection of the claims 50 to 67 of the present application 10/633437 is rejected by me as wrong, just as the reasoning would be rejected by other persons with appropriate skill in the technology of the invention of that application. In addition to being wrong, the reasoning is technically incorrect and inconsistent with the clear disclosure of Kato et al.

4. There are fundamental differences between the flow path shown by the apparatus of Kato et al and the flow path of the apparatus of the present invention as defined by claims 50 to 67. The invention necessitates a runner which, at its end nearer to the die cavity in the flow direction, opens to a controlled expansion region. That is, in the alloy flow direction, the runner is before or upstream of the expansion region. There is a necessary, crucial arrangement between the runner and the expansion region, in that the expansion region has to result in a reduction in alloy flow velocity from the flow velocity of molten alloy received from the runner. The runner needs to have a cross-sectional area for determining the flow velocity of alloy received under pressure, with that cross-section providing a sufficiently high molten alloy flow velocity therein, such as about 140 to 165 m/s. The expansion region has to be such that its cross-section results in a reduction in the runner flow velocity, such as from about 25% to 50%, whereby the alloy state is changed from molten to semi-solid. The resultant semi-solid flow then is able to continue for die cavity fill.

5. The only disclosure in Kato relevant to the above requirements of the invention is the runner 46. This is not followed by an expansion region. In an attempt to show disclosure relevant to the invention, the Examiner asserts that part (45) of Figure 1 of Kato is a controlled expansion region and, while not expressly stated, it can only be the bore of nozzle 3 which is equated by the Examiner as a runner upstream of the expansion region. This reasoning incorrectly takes part (45) literally, as if it was a hollow space which increases in cross-section to the parting

plane between mold parts 43 and 44 and then continues across the parting plane. Basic knowledge in the art of Kato is completely at variance with this and, in particular, with the suggestion that part (45) is an expansion region in any sense relevant to the present invention. Kato et al unambiguously states that part 45 is a sprue. That which is shown as sprue 45 is a simplified outline of a well-known form of sprue for apparatus of Kato et al (and for the prior art over which Kato et al provides an improvement). That form of sprue has been in wide use for many decades and has been adopted in the injection apparatus of Kato et al from well established high pressure die-casting practice. The simplified outline of Kato et al is a sort of symbol or short-hand form of representation which is not intended as a full illustration.

6. In my declaration made on October 18, 2002 in respect of parent application 09/554507, I explained why an article by Lionel Sully, at pages 286 to 295, ASM Handbook, Vol 15 Casting, The Materials Information Society, USA, 1988 was not relevant to the present invention. However, that article illustrates the matters discussed in paragraph 5 above, as can be recognised by reference to the Figures of the attached pages "A" from the article. Figure 1 of the Sully article shows a schematic form of a hot chamber die casting machine in which a sprue, located between the outlet end of the nozzle and the die cavity, is depicted in a simplified form similar to that shown by sprue (45) of Kato et al. For such a machine, Figure 3 shows a more realistic representation in which a sprue bushing defines a passage which increases in cross-section in the direction of alloy flow therethrough. Figure 3 also shows a sprue spreader which fits within the

passage of the sprue bushing. At the left in the lower half (b) of Figure 5 of the Sully article there is depicted an alternative representation of what is shown in Figure 1. The depiction shows a sprue spreader as it extends within a sprue bushing. To the right in lower half (b) of Figure 5, there is shown one form of flow path for a sprue as shown in Figure 3 of the article and similarly with the sprue (4) of Kato et al. The flow is from the nozzle, along a sprue runner cut in the sprue bushing and completed by the sprue spreader, and then to a main runner, tapered runners and gates. A cone shown in broken line depicts the interface at which the sprue bushing and the sprue spreader are in contact, with alloy flow through the sprue in this arrangement possible only along the sprue runner. The cone shown in broken line corresponds to the shape of the region Kato et al specifies as a sprue (45) but, as can be seen, there is no expansion region in which alloy undergoes a reduction in flow velocity. In a variant, which does not use a sprue runner, the cone shown in broken outline represents a spacing between the inner surface of the sprue bushing and the outer surface of the sprue spreader. In that spacing a hollow cone of alloy is able to pass but, despite the hollow cone form, alloy is unable to undergo a reduction in flow velocity. It is standard practice to increase flow velocity from the nozzle through to the gate opening to the die cavity.

7. The apparatus of Kato et al is a low pressure casting machine. This is evident from the indication of Examples of an injection speed of 60 cm/s (0.6 m/s). This injection rate is low for that type of apparatus, as the injection speed usually ranges from 40 to 100 inch/sec (1 to 2.5 m/s) in machine sizes ranging up to

1600 ton. It essentially is not practical to attempt to increase the strength and power rating of the machine to levels remotely approaching a level sufficient for generating an alloy flow velocity at which a change from liquid alloy to semi-solid alloy is enabled. That change necessitates a liquid alloy runner flow velocity of the order of about 150 m/s. This is about 60 times higher than the upper limit of 100 inch/sec (2.5 m/s) and 250 times higher than the injection speed of 60 cm/s (0.6 m/s) disclosed in Kato et al. However, at issue here is not simply unrealistic apparatus requirements, but also the fact that it is liquid alloy flow velocities which are under consideration. Persons skilled in the art know that injecting liquid alloy into a die cavity in high pressure die casting results in die cavity fill as described with reference to Figure 8A of application 10/663437. That is, a stream of liquid alloy is injected through the die cavity, to the far side, after which there is back-filling of the cavity. This stream is very forceful and, to avoid excessive wear of the mold defining the die cavity, the flow velocity of the liquid alloy has to be limited, such as to about 30 to 70 m/s for a magnesium alloy. The person skilled in the art would not contemplate using a significantly higher flow velocity as this is known to cause excessive wear, with the rate of wear increasing with flow velocity. The skilled person, prior to the present invention, would not know that by flow velocity control a change of alloy state to semi-solid could occur at a sufficient flow velocity (subject to other factors being satisfied), and would not contemplate a liquid flow velocity remotely approaching that necessary for that change. A person skilled in the art would reject out of hand a flow velocity of 100 m/s, let alone one of about 150 m/s, as being entirely unacceptable, even if it was

practical to provide apparatus of the type disclosed by Kato et al capable of such a flow velocity.

8. I state above that prior to the invention, a person skilled in the art would not know that a change of alloy state could occur by flow velocity control at a sufficient flow velocity level. The person also would not know that a further factor needing to be satisfied is the need for a reduction in flow velocity from that sufficient level. In fact this is at total variance to normal best practice where the velocity progressively increases along the flow path. The person also would not know that the reduction in flow velocity needs to be to a flow velocity about 25% to 50% less than the sufficient flow velocity. Thus, for a sufficient runner flow velocity of about 160 m/s, the controlled expansion region of the invention needs to reduce the flow velocity to a level of from 85 m/s to 120 m/s. Kato et al is devoid of any disclosure that the sprue 45 is remotely capable of complying with this relationship. However, sprue 45 is not at all in the nature of a controlled expansion region. Figure 1 is a simple, schematic representation of the screw type injection machine, in which sprue 45 is only partially illustrated. It is only because of this, and a lack of understanding of what the representation denotes, that it is possible to incorrectly designate sprue 45 as being an expansion region.

9. At page 2, lines 26 to 28 of application 10/663437, there is reference to work described by Frommer in 1932, and it was that work which provided the basis for Figure 8A of that application. The attached sheet marked "B" shows Frommer's sketch, illustrating the same type of sprue as sprue 45 of Kato et al. In each form

of the Frommer sketch, the left hand mold part shows a frusto-conical sprue bushing, while the right hand mold part shows a tapered sprue spreader or sprue pin received within the sprue bushing. Between the bushing and the spreader there is defined a tapered sprue of annular cross-section. Sheet "B" also illustrates a zinc die casting from "The Die Casting Book" by Arthur Street, published in 1986. The zinc casting has central sprue metal which solidified in a sprue such as shown by Frommer. Sheet "B" has further diagrams, from the book "Die Casting Die Design" by H K Barton, published in 1981, which illustrates similar sprue forms. Sheet "C" illustrates a correct sprue design as stated by "Runner Design", published in 1978 and includes illustrations from "Zinc Die Casting Manual and Directory", published in 1972, each showing similar detail to sheet "A". Also attached and marked "D" is a five page article by Dr Steve LeBeau, published in the March, 2004 issue of "Tooling & Production", showing the same detail in the sprue arrangement in the "Schematic of typical mold configuration for Thixomolding" and "Schematic of stationary die half rigged for Thixomolding". The detail illustrated by Dr LeBeau relates to apparatus of the same type as disclosed in Kato et al, as made clear by the attached article marked "E" by Stephen LeBeau and Joseph Maffia, published in the Fall 2002 issue of Engineered Casting Solutions. All of the sprue designs are similar, and similar to that which is only partially and schematically shown in Kato et al. In each case, the design of the respective sprue has an area significantly larger than the subsequent runner or gate. It is known to me and others skilled in the art that it is normal best practice with such sprues that they <u>decrease</u> in cross-sectional area from the beginning of the sprue right up to the gate. As the cross-

section decreases along the flow path then the flow velocity necessarily increases. Hence, for a gate velocity of 40 m/s, then the sprue would have a lesser flow velocity, such as 15 to 20 m/s. An understanding of Kato et al by a person skilled in the art would lead to a rejection of the interpretation of sprue 45 incorrectly relied on by the Examiner.

10. Having regard to the above matters, it is clear that Kato et al discloses a flow system having a runner and a sprue (45). The sprue enables alloy flow therein to spread laterally, but **not** laterally to result in a reduction in flow velocity from the flow velocity in the runner. It is completely erroneous to state, as in the paragraph bridging pages 2 and 3 of the office action, that there is any disclosure in Kato et al of structure "by which the state of the alloy is changed from a molten state in the runner to a semi-solid state for flow through the gate and into the die cavity". This is contradicted by the whole purpose of Kato et al, which is to heat semi-solid alloy so that it becomes liquid alloy for flow as liquid into the die cavity. Kato et al is incapable of a flow velocity between 140 to 165 m/s for any purpose, with alloy in any relevant state, and to assert that Kato et al is capable of such a flow velocity is to fully misunderstand the purpose and actual teaching of Kato et al. It is correct to state that Kato et al fails to teach the claimed ratio range of 2:1 to 4:1 or a velocity in the sprue (45) of 25% to 50% less than the flow velocity through the runner. Sprue (45) would be understood as defining a part of a flow path which decreases in cross-section and hence which would result in an increase in flow velocity. Also, the asserted modification could not realistically be obvious, since Kato et al is devoid of relevant disclosure and, prior to the present

invention, persons skilled in the art lacked any awareness that control of flow velocity could enable a magnesium alloy to undergo a change from the liquid state to the semi-solid state by a geometric shape change resulting in an appropriate change in alloy flow velocity. The simple fact is that Kato et al has no relevance at all to the present invention, <u>even once the present invention is comprehended.</u>

11. Kato et al, at columns 1 and 2, discusses prior art on thixomolding. The process and apparatus described for this prior art is of the same type as shown in Figure 1 of Kato et al. In the prior art, solid pellets are partially melted to produce a thixotropic solid-liquid phase which is injected into the die cavity. Thus, the prior art process involves "solid in/semi-solid out", with no other state produced. Kato et al points to problems with the die cavity semi-solid fill, and teaches a solution to this. The solution is a simple one which involves further progressive melting of the alloy so that, by the time it reaches what the Examiner evidently refers to as a runner (i.e. the bore of nozzle 3), the alloy is fully molten. Thus, the process of Kato et al involves "solid in/liquid out", with the transition from solid to liquid involving a stage in which the alloy is semi-solid. Kato et al therefore expressly teaches avoidance of problems with semi-solid fill by using liquid fill. The means by which this is achieved is by temperature control, by continuing to heat the alloy. That is, the fully solid alloy is progressively heated until it is fully liquid. It is necessary on one level, to fully understand these matters in order to be able to recognise why the reasons for rejection of the claims in application 10/663437 are wrong.

12. In the office action, there is reference to "applicant's argument and declaration (1.132) submitted on June 8, 2005, regarding Kato et al's apparatus can not be used to cast semi-solid material". This is a complete misunderstanding of applicant's argument and my declaration of 3 June 2005, submitted on 8 June 2005. It is necessary to recognise some simple issues which are either implicitly or explicitly detailed in applicant's response and my declaration of 3 June 2005. These are:

(i) the prior art problem which Kato et al addresses arises from casting semi-solid material,

(ii) the apparatus of Kato et al clearly can be used to cast semi-solid material, by the simple, obvious expedient of not heating the alloy to too high a temperature,

(iii) the simple teaching of Kato et al can be understood as amounting to a teaching of "<u>do not cast semi-solid material</u>", and

(iv) the simple expedient of issue (ii) is to ignore the teaching of Kato et al and to revert to the prior art over which Kato et al seeks to provide an advance.

These issues are understood and taken into account in my declaration of 3 June 2005.

13. My declaration of 3 June 2005, as stated by the Examiner, "argues that the present invention is characterised as liquid in/semi-solid out, with a change in the state of the alloy in the flow system being by control of alloy **flow velocity** rather

than thermally activated". However, it then is said that it is "explained in the previous office action that Kato et al's apparatus is _*capable*_ of changing from a molten state to a semi-solid state, since the flow velocity can be adjusted in Kato's apparatus". This capability attributed to Kato et al is not explained in the previous office action or in the present office action. Rather, in each case, it merely is asserted without substantiation, and it is a false attribution. That is, the apparatus of Kato et al does not have that capability. Before elaborating on why the attribution is false, it is pertinent to consider the assertion in the context of the disclosure of Kato et al.

14. As detailed above, Kato et al teaches the need for die cavity fill with liquid alloy, and avoidance of the cavity fill with semi-solid alloy. The sole means for achieving this change from the prior art is thermal control; that is, control of the operation of successive heating elements to progressively heat the solid alloy to fully melt it. To suggest a capability to change from liquid to semi-solid is not logical in the context of Kato et al. This change would be appropriate only if die cavity fill with semi-solid material was required, but semi-solid fill is the very thing Kato et al seeks to avoid. That is, the examiner is suggesting the apparatus of Kato et al has a capability to achieve a result Kato et al teaches should be avoided. It seems as if the Examiner is postulating the sequence of steps of:

(i) melting solid alloy to produce semi-solid alloy,

(ii) further melting the semi-solid alloy to produce liquid alloy, and

(iii) changing the liquid alloy back to semi-solid alloy,

with these three stages occurring at successive locations between the solid inlet and the die cavity. If this is being postulated, it needs to be recognised that:

(a) step (iii) results in die cavity fill with semi-solid alloy, which Kato et al teaches avoiding;

(b) if, however, die cavity fill with semi-solid alloy was required (as in the prior art addressed by Kato et al), it would be sufficient to stop at step (i) and not proceed to steps (ii) and (iii); and

(c) there is no disclosure at all in Kato et al as to how step (iii) could possibly be achieved.

Of course, it was known prior to Kato et al that liquid alloy could be changed to semi-solid alloy. This was by <u>thermal control</u> in which the alloy was subjected to shear while being cooled; i.e. the converse of the thermal control used by Kato et al. It is difficult to envisage how this could be utilised in the apparatus of Kato et al but, in any event, it would be contrary to Kato et al for reason (a) above. Moreover, such thermal control has no relevance to the <u>flow control</u> required by the present invention.

15. I turn now to the suggestion that the apparatus of Kato et al is <u>*capable*</u> of changing from a liquid to a semi-solid state. It is clear to me, and would be clear to others with appropriate skill in the technology, that the apparatus of Kato et al <u>**does not possess that capability**</u>. This can be appreciated from a number of perspectives, a first one of which relates to the actual disclosure of Kato et al. In relation to that disclosure the following matters are relevant:

(i) Kato et al is devoid of any disclosure on changing from a liquid alloy to a semi-solid alloy;

(ii) Kato et al teaches the need to avoid die cavity fill by semi-solid alloy and, instead, to achieve die cavity fill with liquid alloy;

(iii) Kato et al teaches thermal control, i.e. controlled heating along the length of the screw barrel, to achieve progressive changes from solid alloy at an inlet end of the screw, to semi-solid down-stream from the inlet end and finally to liquid alloy at the outlet end of the screw;

(iv) The teaching of Kato et al on thermal control has nothing to do with flow velocity control;

(v) Kato et all is devoid of any teaching on flow velocity control relevant to any issue;

(vi) Kato et al simply states that the liquid alloy has an injection speed of not less than 50 cm/s (0.5 m/s), with each Example indicating the injection speed is set at 60 cm/s (0.6 m/s), but nothing of any relevance is attributed to this beyond the implication that at too slow a speed, the alloy will freeze up and stop the apparatus.

Kato et al is devoid of any disclosure of using alloy flow velocity control to achieve a change from molten to semi-solid alloy. Given this, it is pertinent to query what modification of Kato et al is necessary in order that, instead of performing as Kato et al teaches, the apparatus should perform to change the liquid alloy to semi-solid alloy. This query is addressed in the following.

16. At the outset in addressing the query on possible modification in the apparatus of Kato et al, it is appropriate to understand that it was not known prior to the present invention that flow velocity control could enable a change in a magnesium alloy from a molten state to a semi-solid state. Patents have been granted on the present invention in 11 countries (including Europe and Russia) while applications are pending in a further 8 countries. In none of these countries nor in the originating PCT application has there been cited any prior art which, in any sense, suggests that flow velocity can be used to achieve that change. Thus, the query on possible modification in the apparatus of Kato et al is one which needs to be answered in ignorance of what the modification might conceivably achieve. That is, the possible modification is not one which can be suggested with knowledge of a particular end result to be achieved, since the end result in question (a change from molten to semi-solid alloy by flow velocity control) was not known to be possible. Also, a modification clearly is necessary since, when the apparatus of Kato et al is operated as taught by Kato et al, that change does not occur.

17. What then can reasonably be done in order to enable the apparatus of Kato et al to perform in accordance with the capability the Examiner asserts that it has? Clearly, in order that the apparatus can perform differently, something has to be modified in the operation of the apparatus, or in the form of the apparatus or in the combination of both the operation and form of the apparatus. The Examiner makes no suggestion as to the modification. This is despite it being stated in my declaration of 3 June 2005, on the basis of my experience in the technology and

my knowledge of the present invention, that the apparatus of Kato et al is not capable of achieving a change from liquid alloy to semi-solid alloy. My "knowledge in the technology" includes personal experience with apparatus of the type disclosed in Kato et al; apparatus of this type having been proposed, such as for the prior art considered by Kato et al, for about 30 years. I correctly stated in my declaration of 3 June 2005 that the apparatus of Kato et al does not have the capability asserted by the Examiner. While there are numerous options for modification of the apparatus of Kato et al, I consider there is no modification that reasonably can be adopted in order to confer on the apparatus the capability to cause liquid alloy to change its state to semi-solid alloy except by thermal control. However, rather than discuss various possible options, it is pertinent simply to consider the only option relevant to the present invention, despite the fact that this necessitates reliance on a knowledge of the present invention. That is, with the benefit of hindsight provided by the present invention, it is appropriate to consider the issue of flow velocity control in relation to the apparatus of Kato et al, even though without that hindsight there is no motivation or reason to expect that flow velocity control would enable any useful modification of that apparatus, let alone a change in alloy state. Thus, even if the apparatus of Kato et al was to be modified by replacing the sprue 45 with an expansion region of the shape required by the invention, that expansion region substituted for sprue 45 would not result in molten alloy changing to the semi-solid state. This is because the apparatus of Kato et al is not capable of generating enough pressure for achieving the required flow velocities upstream of and in the substituted

expansion region. Further reasons are apparent from my explanation provided in paragraphs 4 to 8 above.

18. The foregoing comment is made primarily with reference to claims 50, 62 and 66, in relation to each of which the pressure casting machine would be a hot chamber or a cold chamber die casting machine. Each of these types of die casting machines is recognised in the art as quite distinct from the type of machine to which Kato et al relates. The well known differences between die casting machines on the one hand and the machine of Kato et al on the other hand are significantly further increased by virtue of the matters detailed above. Claims 51 to 61, 63 to 65 and 67 further distinguish the invention as follows:

(i) Contrary to claim 51, the sprue (45) of Kato et al is neither a controlled expansion region nor adjacent to a gate – in Kato et al, there is no reference to a gate, but a conventional gate would be spaced from sprue (45) by runner (46).

(ii) There is no disclosure of Kato et al of a gate with a larger cross-sectional area than runner (46) or (of more relevance) than the bore of nozzle (3) – contrary to claim 52 – such that flow velocities are the converse of requirements for the invention;

(iii) Particularly given point (ii), the ratio range of claim 53 is completely at variance with any disclosure of Kato et al which must be understood as necessitating a gate which is a constriction;

(iv) As Kato et al does not disclose a controlled expansion region at all, the reference is still further removed from either claim 54 or claim 55.

(v) Kato et al is not relevant to the requirements of any of claims 56 to 60, claims 63 to 65, and claim 67 for reasons I have detailed earlier in this declaration.

(vi) Given that Kato et al teaches the injection of molten alloy, die cavity fill by moving fronts of semi-solid metal, as required by claim 61, is not possible. In Kato et al, molten alloy will enter the die cavity as a thin stream determined by the gate cross-section.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements are made with the knowledge and that wilful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such wilful false statements may jeopardise the validity of this application or any patent issuing thereon.

(Morris Taylor MURRAY)

18/2/06

Dated

Die Casting

Lionel J.D. Sully, Edison Industrial Systems Center

DIE CASTING is characterized by a source of hydraulic energy that imparts high velocity to molten metal to provide rapid filling of a metal die. The die absorbs the stresses of injection, dissipates the heat contained in the metal, and facilitates the removal of the shaped part in preparation for the next cycle. The hydraulic energy is provided by a system that permits control of actuator position, velocity, and acceleration to optimize flow and force functions on the metal as it fills the cavity and solidifies.

Die Casting Processes

The variety in die casting systems results from trade-offs in metal fluid flow, elimination of gas from the cavity, reactivity between the molten metal and the hydraulic system, and heat loss during injection. The process varieties have many features in common with regard to die mechanical design, thermal control, and actuation. Four principal alloy families are commonly die cast: aluminum, zinc, magnesium, and copper-base alloys (Table 1). Lead, tin, and, to a lesser extent, ferrous alloys can also be die cast. The three primary variations of the die casting process are the hot chamber process, the cold chamber process, and direct injection.

The hot chamber process is the original process invented by H.H. Doehler. It continues to be used for lower-melting materials (zinc, lead, tin, and, more recently, magnesium alloys). Hot chamber die casting places the hydraulic actuator in intimate contact with the molten metal (Fig. 1). The hot chamber process minimizes exposure of the molten alloy to turbulence, oxidizing air, and heat loss during the transfer of the hydraulic energy. The prolonged intimate contact between molten metal and system components presents severe materials problems in the production process.

The cold chamber process solves the materials problem by separating the molten metal reservoir from the actuator for most of the process cycle. Cold chamber die casting requires independent metering of the metal (Fig. 2) and immediate injection into the die, exposing the hydraulic actuator for only a few seconds. This minimal exposure allows the casting of higher-temperature alloys such as aluminum, copper, and even some ferrous alloys.

Direct injection extends the technology used for lower-melting polymers to metals by taking the hot chamber intimacy to the die cavity with small nozzles connected to a manifold, thus eliminating the gating and runner system. This process, however, is still under development.

Process control in die casting to achieve consistent high quality relates to timing, fluid flow, heat flow, and dimensional stability. Some features are chosen in die and part geometry decisions and are therefore fixed; others are defined by the process at the machine and can be adjusted in real time. All are related and therefore must be dealt with in parallel; the best die castings result from an intimate interrelationship between product design and process design.

Product Design for the Process

Product design and die design are intimately related. The principal features of a die casting die are illustrated in Fig. 3. The

Table 1 Compositions of selected die casting alloys

Alloy	Principal alloying elements, %(a)								
	Al	Cu	Fe	Mg	Mn	Pb	Si	Sn	Zn
Aluminum alloys									
A360	rem	0.60	1.0	0.40–0.60	...	...	9.0–10.0	...	0.40
A380	rem	3.0–4.0	1.0	0.10	...	...	7.5–9.5	...	2.9
A383	rem	2.0–3.0	1.0	0.10	...	...	9.5–11.0	...	2.9
A384	rem	3.0–4.5	1.0	0.10	...	...	10.5–12.0	...	2.9
B390	rem	4.0–5.0	1.0	0.5–0.65	...	...	16.0–18.0	...	1.4
A413	rem	1.0	1.0	0.10	...	...	11.0–13.0	...	0.40
518	rem	0.25	1.1	7.6–8.5	...	...	0.35	...	0.15
Copper alloys									
C85800	0.25	57 min	0.50	...	0.25	1.5	0.25	1.50	31 min
C87900	0.15	63 min	0.40	...	0.15	0.25	0.75–1.25	0.25	rem
C87800	0.15	80 min	0.15	0.01	0.15	0.15	3.75–4.25	0.25	rem
Magnesium alloys									
AZ91B	8.3–9.7	0.35	...	rem	0.13	...	0.50	...	0.13
AM60A	5.5–6.5	0.35	...	rem	0.13	...	0.50	...	0.22
AS41A	3.5–5.0	0.06	...	rem	0.20	...	0.50	...	...
Zinc alloys									
AC40A	3.9–4.3	0.10	0.075	0.025–0.05	...	0.004	...	0.002	rem
AG41A	3.5–4.3	0.25	0.10	0.02–0.05	...	0.005	...	0.003	rem
Alloy 7	3.9–4.3	0.75–1.25	0.075	0.03–0.06	...	0.004	...	0.002	rem
ILZRO 16	3.5–4.3	0.75–1.25	0.10	0.03–0.08	...	0.005	...	0.003	rem

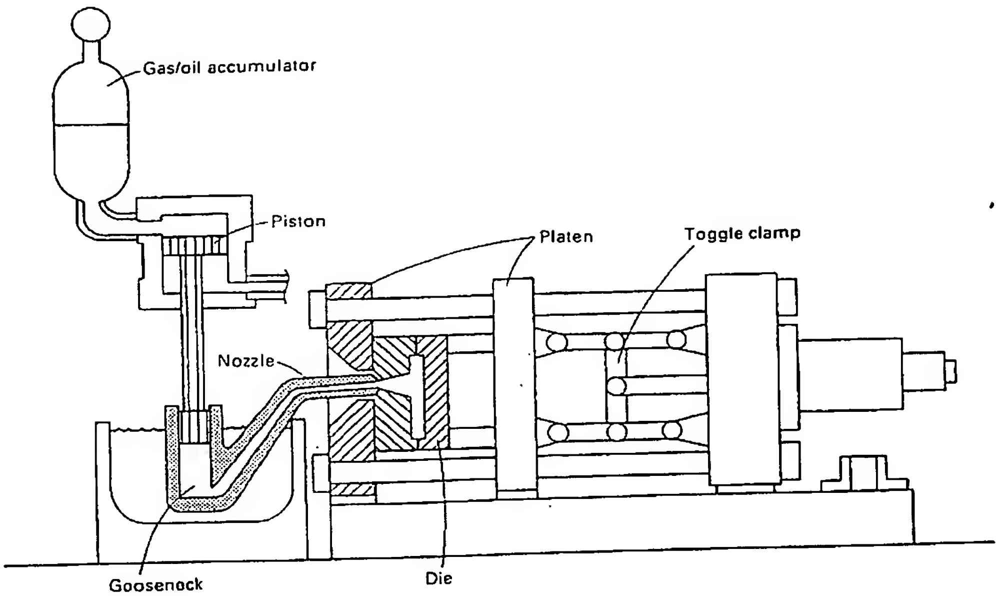


Fig. 1 Schematic showing the principal components of a hot chamber die casting machine

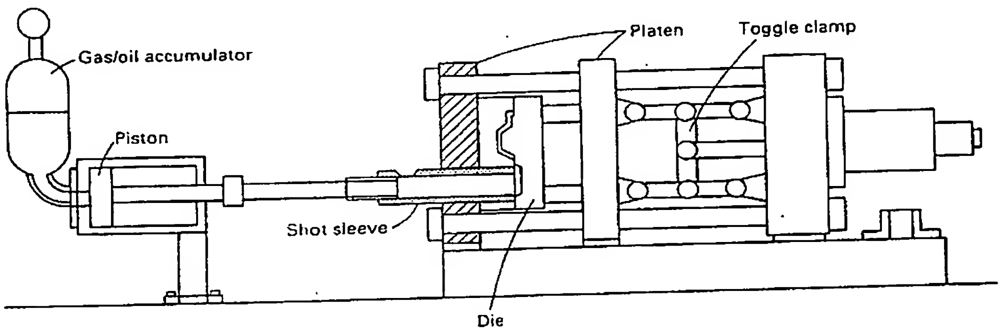


Fig. 2 Schematic showing the principal components of a cold chamber die casting machine

high-speed nature of the process allows the filling of thin-wall complex shapes at high rates (of the order of 100 parts per hour per cavity). This capability places additional demands on the casting designer because traditional feeding of solidification shrinkage is almost impossible. The inability to feed in the traditional sense demands that machining stock be kept to a minimum; high-integrity surfaces should be preserved.

A factor in cost is the parting line topology. The parting line is the line on the casting generated by the separation between one die member and another. The simplest and lowest-cost die has a parting line in one plane. Casting design should be adjusted if possible to provide flat parting lines. Draft is required on the die casting walls perpendicular to the parting line or in the direction of die motion (Fig. 4). An important characteristic of good design is uniform wall thickness, which is necessary for obtaining equal solidification times throughout the casting. Die castings have wall thicknesses of about 0.64 to 3.81 mm (0.025 to 0.150 in.), depending on casting shape and size (Table 2). Bosses, ribs, and filleted corners always cause local increases in section size. In particular, bosses that must be machined require consideration of the entire product-manufacturing cycle. The machinist will find it easier to drill into a solid boss; cored bosses may require floating drill heads in order to align the drill with the cast tapered hole that preserves the high-integrity skin of the casting.

Cores and slides provide side motions for undercuts. A core body is generally round and buried within the cover or ejector die. A slide body has a rectangular or trapezoidal shape and crosses the parting line of the die. As with the cover and ejector dies, the impression steel is often separate from the holder steel. Cores and slides are actuated by various methods, including hydraulic cylinders, rack and pinion, and angle pins. Innovative die design permits radial die motion at a price of die expense. There are die casting processes that use complex-shaped disposable cores similar to those in other gravity casting processes. Cores and slides provide the casting designer with tremendous flexibility at the expense of an increase in die complexity. A standard set of cores—fixed core pins for small holes that are screwed in, or bolted-in inserts—can be used to reduce die construction cost and to permit rapid replacement.

Loose Pieces and Inserts. In certain cases, a reentrant shape needs to be cast into the part where there is no space for core/slide mechanisms. In such a case, the die designer can use a loose piece. A loose piece is placed in the die before each shot is made. It is then ejected from the die with the casting and separated manually or by fixture. Although it provides design flexibility, the load/unload sequence required for loose pieces slows the process, thus increasing cost.

Similarly, the die casting process can allow the part designer great flexibility in local material properties by the use of cast-in inserts of other materials, such as steel, iron, brass, and ceramics. The bond between insert and casting is physical, not chemical, in nature. Therefore, the insert should be clean and preheated. The insert should be designed to prevent pullout or rotation under working loads; knurling, grooves, hexagons, or flats are commonly used for this purpose. Proper support of hollow inserts will prevent crushing of the insert under the high metal injection pressure. The wall thickness of the casting surrounding an insert should be no less than 2.0 mm (0.080 in.) to prevent cracking by shrinkage, hot tearing, and excessive residual stresses.

Trimming. The die cast part is ejected from the die with a variety of appendages (gates, overflows, vents, flash, and robot grasping lugs) that must then be removed. This secondary process is called trimming. Although trimming can be done manually, the high production rates characteristic of die casting demand automation. Trim presses are used to remove the excess material. Castings are often trimmed immediately after the casting process because their higher temperature reduces the strength of the metal.

Trimming conditions directly influence the design of the part and the die casting process, especially gating and parting line definition. Trimming is facilitated by flat parting lines. The relatively rough edge that results from trimming may be acceptable and is often left as is. In some cases, this rough edge is not acceptable and must be removed by machining or grinding. The direction of flash must be such that the edge is machinable.

Dimensional variation is determined by die design, the accuracy of die construction, and process variation. The most accurate

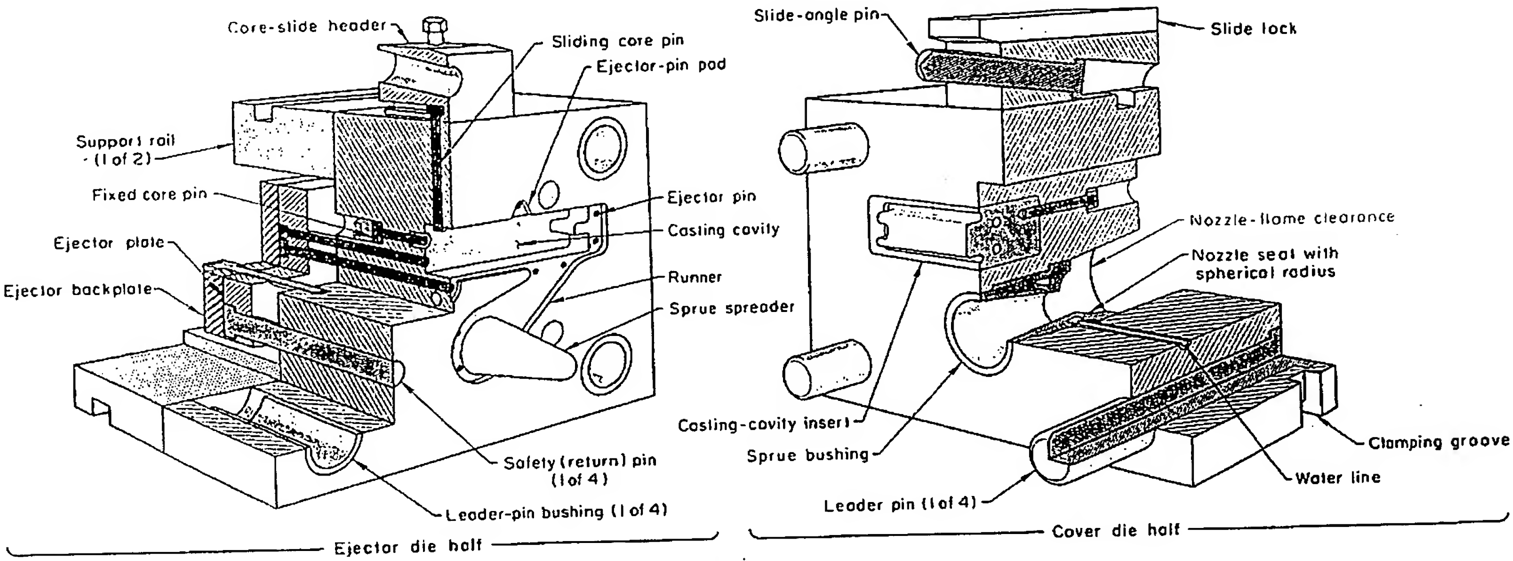


Fig. 3 Components of a single-cavity die casting die for use in a hot chamber machine

dies are those machined using computer numerical control methods. Close control of alloy composition, temperature casting, time, and injection pressure will lead to more consistent casting dimensions. The minimum variation in dimensions is required for those features contained entirely within one die half. Table 3 lists the tolerances on linear dimensions recommended by the American Die Casting Institute (ADCI); Tables 4 and 5 list additional tolerances recommended by ADCI. Therefore, machining locators should ideally be placed in the same die half. Tolerances are a function of casting size and projected area. Features across parting lines have added variation because of the accuracy of repeated die closing. Die temperature, machine hydraulic pressures, and die cleanliness are the principal factors to be controlled. Finally, further dimensional variation occurs if the feature is in a moving die member such as a slide or core.

In summary, a cost-effective die casting demands proper attention to the dimensional variation of the process. Inattention to dimensional factors will lead to an inability to provide consistent products within economic process conditions. The product designer and the die caster must therefore initiate a dialog early in the product cycle.

Gating

The first step in the process sequence is the supply of the molten alloy to the casting machine and its injection into the die. The fluid flow is divided into three considerations: metal injection, air venting, and feeding of shrinkage.

Metal Injection

The distinguishing characteristic of the die casting process is the use of high-velocity injection. The short fill time (of the order of milliseconds) allows the liquid metal to move a great distance despite a high rate of heat loss. The elements of a typical metal gating system are illustrated in Fig. 5.

Proper process performance depends on the delivery of molten metal with high quality as defined by temperature, composition, and cleanliness (gas content and suspended solids). The molten alloy is prepared from either primary ingot or secondary alloys. A melting furnace is used to provide the proper temperature and to allow time for chemistry adjustment and degassing. The alloy is often filtered during transfer to a holding furnace at the casting machine.

The Injection Chamber. Three components make up the injection chambers used for the three types of die casting: the shot sleeve, the gooseneck, and the nozzle (Fig. 1, 2). The cold chamber shot sleeve (Fig. 2) is unique. Initially, it is only partially filled to prevent splashing and to allow for metering error, and it must be filled by slow piston movement to avoid wave formation and air entrainment. Then, for all three chambers, the hydraulic piston rapidly accelerates the molten metal to the desired velocity for injection (Fig. 6). Most die casting machines provide the ability to control the piston acceleration in a linear fashion. Parabolic velocity curves are also available on some controls. This phase of injection can be accomplished in several steps. The third phase of injection is activated as the cavity is close to being filled. This intensification phase draws on an accumulator of high-pressure hydraulic fluid or multiplies pressure using conventional

Table 2 Minimum section thicknesses for die castings

Surface area of casting(a)		Minimum section thickness for: Tin, lead, and zinc alloys		Aluminum and magnesium alloys		Copper alloys	
cm²	in.²	mm	in.	mm	in.	mm	in.
Up to 25	Up to 3.875	0.635	0.025	0.81	0.032	1.52	0.060
25–100	3.875–15.5	1.02	0.040	1.27	0.050	2.03	0.080
100–500	15.5–77.5	1.52	0.060	1.78	0.070	2.54	0.100
Above 500	Above 77.5	2.03	0.080	2.54	0.100	3.05	0.120

(a) Area of a single main plane

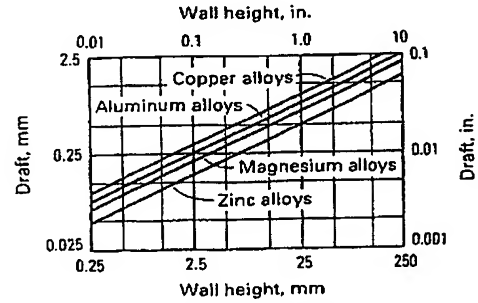
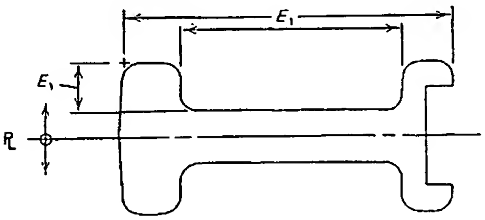


Fig. 4 Minimum drafts required for inside walls of die castings made from four different types

Table 3 Recommended tolerances on as-cast linear dimensions of die castings

Additional tolerances are listed in Tables 4 and 5.



The tolerance on a dimension E_1 will be the value shown in the tables for dimensions between features formed in the same die part. The tolerance must be increased for dimensions of features formed between moving die parts (see Tables 4 and 5).

Length of dimension E_1, in.	Basic tolerance (in.) for: Zinc alloy castings	Aluminum and magnesium alloy castings	Copper alloy castings	Additional tolerance(a) (in.) for each additional inch of dimension E_1 for: Zinc alloy castings	Aluminum and magnesium alloy castings	Copper alloy castings
Noncritical dimensions						
Up to 1	±0.010	±0.010	±0.014	. . .	. . .	. . .
1–12	. . .	. . .	. . .	±0.0015	±0.002	±0.003
Above 12	. . .	. . .	. . .	±0.001	10.001	. . .
Critical dimensions						
Up to 1	±0.003	±0.004	±0.007	. . .	. . .	. . .
1–12	. . .	. . .	. . .	±0.001	±0.0015	±0.002
Above 12	. . .	. . .	. . .	±0.001	±0.001	. . .

(a) Example: an aluminum alloy casting would have a tolerance of ±0.010 in. on a critical 5.000 in. dimension E_1 (that is, the basic tolerance of ±0.004 in. + 4 (0.0015) = ±0.010 in.). Source: Ref 1

piston intensifiers. This increases the pressure on the metal to force the rapidly freezing alloy into incipient shrinkage cavities.

Sprues and Runners. The sprue provides a smooth transition from the shot sleeve or nozzle and promotes high cooling heat flow after injection is complete. The runner carries the flowing metal from the injection chamber to the desired location(s) on the casting periphery. Runners are not used in direct injection. Heat loss, unnecessary turbulence, and die erosion can be minimized by proper attention to basic hydraulic principles when designing runners. Typical runners are therefore round or nearly square trapezoidal in section to minimize surface area and heat loss. There is a distinct change in section from the thick runner to the thin gate. A change in flow direction also often occurs. The approach section is the means for achieving these two needs. The shape of this section of the flow channel often provides the name of the gate, for example, chisel gate or fan gate. The use of tapered tangential runners eliminates this approach feature.

The gate is the controlling entry point into the casting. The gate serves a fluid flow need, but it must later be removed from the casting by trimming. Therefore, the gate cross section should be the smallest in the gating system. The cross section is determined by the desired fill time and flow rate that the casting machine can provide. A number of methods are available for calculating gate area; these are discussed below.

The shape of the part is primarily governed by the end use, not by fluid flow considerations. Indeed, the die casting process excels in very complex near-net shape configurations. The high-velocity inertia-driven flow, combined with rapid heat loss and partial freezing during fill, eliminates the possibility of a rigorous fluid mechanics solution. However, the die caster must always attempt to understand the flow in the part cavity.

The overflow is the final component in the fluid flow system. Although they add to the weight of remelt, overflows do serve a variety of purposes. They can act as a reservoir for metal to be removed from the cavity, and they can provide an off-casting location for ejection pins, robot holds, or instrumentation points.

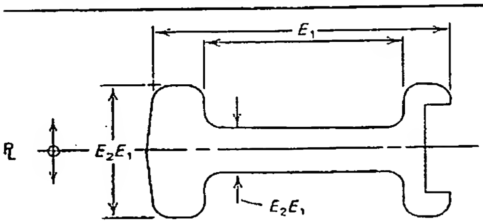
Gating System Design. Several methods are available for designing gating systems. Design of the gating system is always a compromise. Unlike the flow of polymers or metal flow in forging, the high-velocity metal flow of die casting, combined with heat loss and simultaneous solidification, cannot be rigorously solved with computational methods. Therefore, various methods have been developed to provide the die caster with tools to address the problem on a sound, consistent basis. All of these methods attempt to take into account the influence of the following key variables:

- Part shape
- Internal quality
- Surface quality
- Mechanical properties
- Die temperature
- Die erosion
- Die material
- Die venting
- Metal temperature
- Metal fluidity
- Metal heat content
- Metal microstructure

Since the invention of the die casting process, many die castings have been successfully made with gating systems designed by experience only. Each company has a reservoir of this closely guarded experience. Trial-and-error adjustments at the casting machine are frequently part of the learning. However, the decline of the presence of the artisan in the foundry is forcing a move toward analytically based gating design, but the analysis base is still tempered with the fine tuning of experience. This is especially true in gate location and local angle

Table 4 Recommended parting line tolerances for die castings

Tolerances given in this table are to be added to the basic tolerances given in Table 3. See also Table 5.



The tolerance on dimensions such as E_2E_1, which are perpendicular to the parting plane, will be the value shown in the table plus the linear tolerance from Table 3. The value chosen from the table depends on the projected area of the part. Additional tolerances in the case of other moving die parts are shown in Table 5.

Projected area of casting, in.²(a)	Additional tolerance(b) (in.) for: Zinc alloy castings	Aluminum and magnesium alloy castings	Copper alloy castings
Up to 50	±0.004	±0.005	±0.005
50–100	±0.006	±0.008	. . .
100–200	±0.008	±0.012	. . .
200–300	±0.012	±0.015	. . .
300–500	10.016	±0.020	
500–800	±0.020	±0.025	. . .
800–1200	±0.025	±0.030	. . .

(a) Projected area is the area of the part in the parting plane. (b) Example: an aluminum die casting with a projected area of 75 in.² would have a tolerance of ±0.018 in. on a critical 5.000 in. dimension E_2E_1 (that is, ±0.008 in. for 75 in.² plus the basic linear tolerance of 0.010 in.). See Table 3. Source: Ref 2

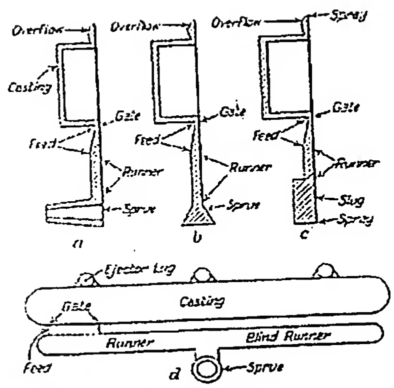


Fig. 1. Diagrams showing Sprues, Runners, and Gates on Centre-gated, Edge-gated and Cold-chamber Castings. The Terms "Runner", "Feed", "Gate" and "Sprue" are also applied to the corresponding Channels in the Die.

HK Barton "Die casting die design" 1981.

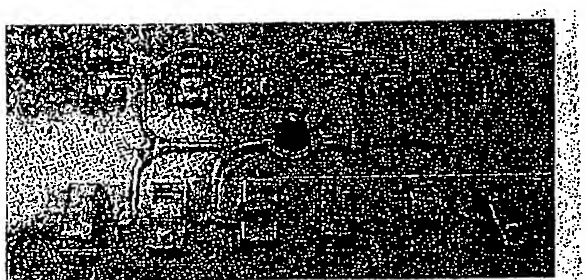


Fig. 8.4. Spray of 13 zinc alloy diecastings produced on a 250 ton Ex-Cell-O machine with automatic drop-through on an 8-9 second cycle. (Courtesy EX-CELL-O B&T and The Strombecker Corporation.)

Arthur Street"The Die Casting Book" 1986

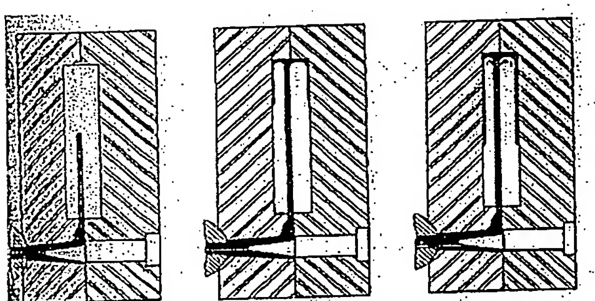
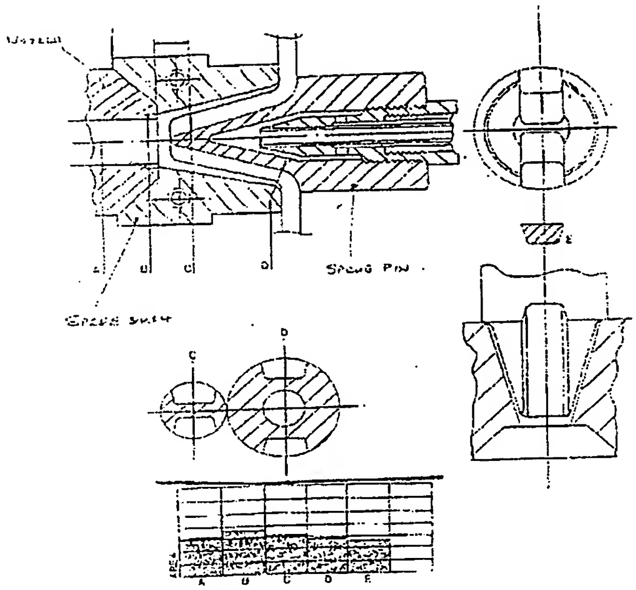
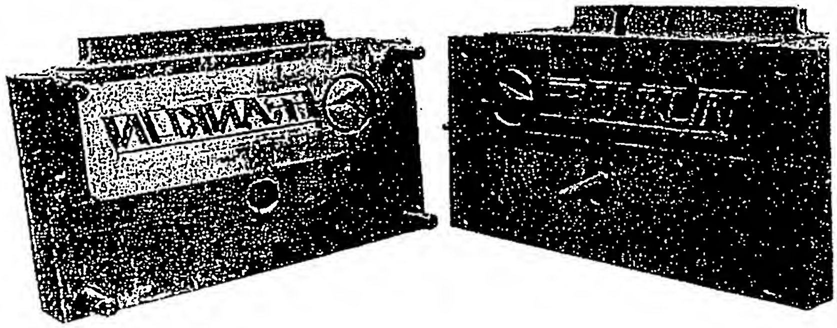


FIG. 3.1. Sketch illustrating Frommer's theories.

Frommer's sketch (1932)



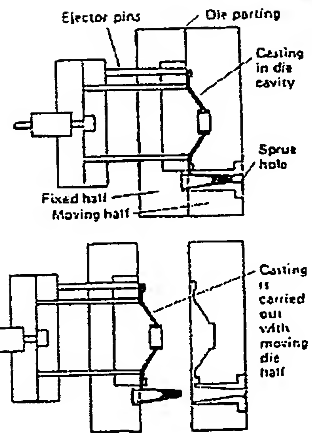
Correct Sprue Design as stated by “Runner Design” 1978.

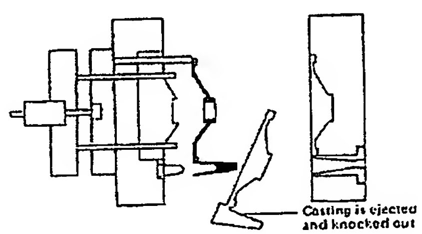


Die tools for zinc die casting, above, showing highly finished die cavity in fixed half, left. Dowell pins for location can be seen at corners, sprue hole centre. Moving die half, right, shows sprue pin and mating holes for dowell pins. Holes for ejector pins are visible behind lettering in impression.

Right, typical sequence of events in a fully automatic die casting cycle.

1 Die is closed and locked, molten zinc is injected through sprue hole into die cavity.
2 Die opens, solid casting is carried out with moving die half.
3 Ejector pins push casting off moving half and die is ready to close to begin another cycle.





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Anon, "Zinc Die Casting, Manual and Directory" 1972

All of the above designs predate Kato. The sprue area of Kato's patent is identical to the normal practice of injecting metal along a conical region which forms a cast part that is easily removed.

The design of these conical regions, called sprues, is that the area of the sprue is significantly larger than any of the subsequent runner or gate. It is normal best practice that the areas decrease from the beginning of the sprue right up to the gate. If the area decreases along the flow path then the velocity also increases. Hence, if the gate velocity is 40 m/s then it would be expected that the sprue or conical area would have a velocity of approximately 15-20 m/s.

T&P TOOLING & PRODUCTION

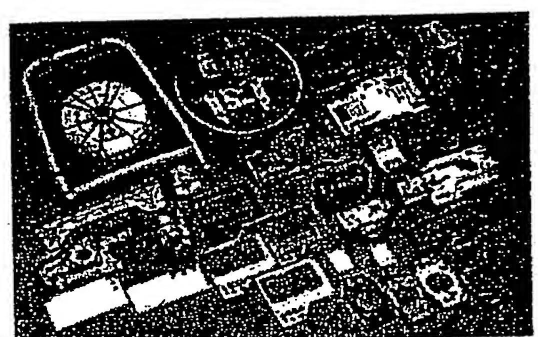
TOOLING

Thixomolding benefits parts makers

Design tips for tooling makers

By Dr. Steve LeBeau
VP Sales and Marketing Thixomat Inc.

With more than 50 licensees worldwide and over 250 machines in operation, Thixomolding has enjoyed significant growth in times when competing processes such as die casting and injection molding have seen their markets shrink. Before the Thixomolding process was commercialized in 1990, ultra-thin wall, dimensionally-stable, low-porosity magnesium components were costly if not impossible to manufacture using the die casting process.



Variety of parts produced by the Thixomolding process.

With Thixomolding, magnesium parts with walls as thin as 0.5 mm can be produced competitively for such end users as the electronics market where lightweight, stiff, strong, and heat-dissipating components that meet complex tight tolerances are required. Although Thixomolding has seen its greatest growth in the consumer electronics market, other applications are being found for notebook computers, mobile telephones, digital projectors, automotive parts, digital cameras, office equipment, and portable electric hand tools, among a host of others.

Thixomolding is a marriage of the die-casting and plastic injection molding processes to produce netshape components. It takes the best of each process and creates a totally new way of molding metal

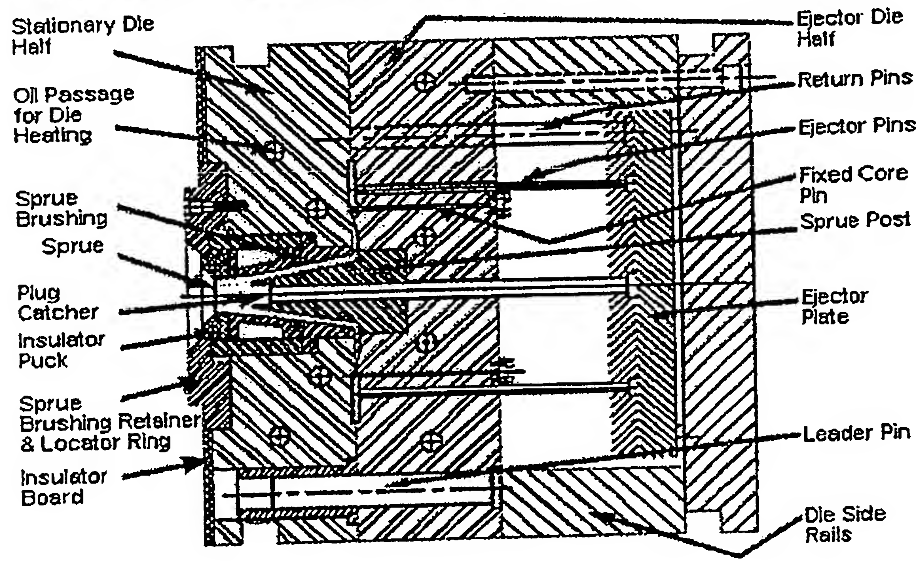
components. Though the process was developed mainly for magnesium alloys, several zinc alloys have also been run successfully and an aluminum development program is well underway.

Thixomolding is a high-speed, semi-solid magnesium injection molding process that is environmentally friendly. In a single step, the process transforms room temperature magnesium chips—heated to a semi-solid slurry inside a barrel and screw—into precision-molded components. No sintering or de-binding steps are required as in the MIM (metal injection molding) process to complete component densification. Components after cooling in air are ready for trimming and assembly or secondary operations. They typically exhibit as-molded densities in the range of 98-99 percent. This low porosity level makes them good candidates for secondary operations such as coating or plating without blistering or out-gassing.

General design tips for Thixmolded components

Draft:	Draft 0.5 to 3 degrees…Normal is 1 degree…Zero draft is possible if sufficient ejection surface is available.
Design or pattern shrink:	This is the shrink factor that is applied to the print dimensions when cutting the tooling to account for dimensional changes during molding and cooling. +0.5 percent or +0.005" per inch of dimension. This shrink factor is consistent in all directions.
Ribs:	Use ribs to strengthen sections and reduce mass required. Ribs should be from 0.5 to 1.0 times the adjoining wall thickness.
Fillets and radaii:	"T" junctions: R=wall thickness "X" junctions: 45 degree angle R inside=0.7 x wall thickness R outside=1.5 x wall thickness 30 degree angle R inside=0.5 x wall thickness R outside=2.5 x wall thickness "L" junctions: R inside=wall thickness R outside= 2 x wall thickness Note: Too large of a fillet radius can cause porosity and a reduction in strength
Cross sections:	Design wall thickness as uniform as possible. Generally, rapid changes in wall thickness cause porosity and internal shrink- age. The Thixomolding process is better equipped to handle changes in wall thickness because the process can vary the percentage of solids and

	reduce cross section porosity. Higher percentage of solids reduces porosity in heavy sections.
Ejector pin marks:	The designer should consult with the customer to determine where ejector pin marks are allowed and where cosmetic surfaces are located.
Thixomolding Machine clamping forces:	Machines sizes 75 to 650-ton: 7 tons per square inch of component projected area Machines over 650 tons: 6 tons per square inch of component projected area Component projected area is the total projected area of all parts in all cavities plus an allowance for the projected area of the gating.



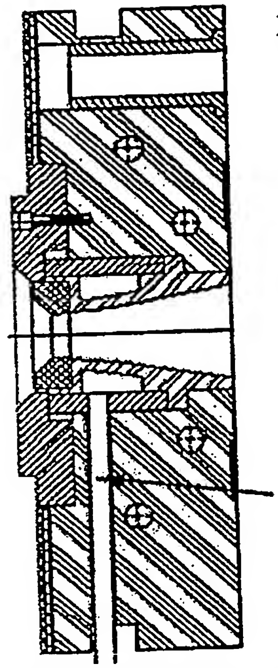
Schematic of typical mold configuration for Thixomolding

Tooling up for the process

Tooling for the Thixomolding process is very similar in construction to die cast dies and injection molds. Mold makers that are making high-quality die cast dies or injection molds can build tooling for Thixomolding. The construction methods are the same as for die cast tooling. There are only a couple of differences from plastic injection molds. Tools can be single- or multiple-cavity depending on the volume requirements for the products.

Thixomolding tooling needs to be made with slightly more support and heavier tool blocks than traditional plastic tools. The second difference is that plastic tools typically have cooling lines while Thixomolding uses these same lines to heat (hot oil) the tool during operation. Typically, hot oil temperatures for the tooling run in the range of 400-450 F (204-232 C). Large core slides may need to be heated while smaller ones will retain enough heat to remain functional. Sprue bushings may be cooled with a separate oil circuit to reduce die cycle

times.



Schematic of stationary die half rigged for Thixomolding

Materials for mold construction include 4140 pre-hardened steels for tool blocks A & B sides; H-13 Rc 44-46 for production cavity inserts; and P-20 for prototype or market entry tooling (good for about 5,000 shots). Typical tool actions: slides, mechanical or hydraulic, lifters, sleeved ejector pins. Clamping forces from 5-7 tons per square inch of component projected area should be used to determine machine size.

The die layout schematic shows many features that are typical to die cast and injection molding tools; however, a few features are unique to Thixomolding. The plug catcher is a reverse-taper cold well that catches and holds the frozen magnesium plug from the machine nozzle each cycle. The insulator puck is made from high strength low conductivity steel. Its function is to act as a thermal barrier between the hot nozzle and the relatively cool sprue bushing.

Unit dies or MUD dies have been successfully used by licensees to reduce the cost of prototype and market entry tools for the customer.

A separate oil cooling line may be run into the sprue bushing to draw heat from the mass of metal in the sprue. This allows the die to be opened quicker and enhances productivity.

New developments, hot runners etc.
Hot runner systems similar to those used in plastics are now being used in a number of Thixomolding applications. The temperature is significantly higher in the manifold system when magnesium is injected. These hot runner systems are significantly different in heat capacity and operating sequence from typical plastic systems.

Benefits of hot runner systems include:

- Significant improvements in cycle times
- Increased yield and simplified gating
- Improved component quality
- Reduction of machine size required

Both single and multiple drop systems have been designed into high production Thixomolding tools.

Vacuum systems are incorporated into tooling when the components to be produced have fine detail, deep bosses, heavy sections (requiring low porosity), or ultra-thin walls. Vacuums are usually drawn in the range of 5" to 20" of mercury. Adding vacuum assist to a tool will add as much

as 2 to 3 seconds to the cycle time, depending on how long it takes to draw the vacuum down to the desired levels.

Thixomolding machines are equipped to incorporate vacuum assist into their cycles. When vacuum assist is turned on in the control system, the machine will close, draw the vacuum in the die cavity to the pre-set level, then inject the metal into the die cavity. If the pre-set vacuum level is not reached for some reason, the machine cycle will not continue.

The vacuum is usually drawn through a system of vents coming off the cavity. Chill blocks are used to ensure that no liquid metal is drawn into the vacuum pump. It is important to draw the vacuum through one set of vents from the cavity and use a separate set of vents running to the sensor side of the tool. This will ensure that the die cavity has reached the pre-set vacuum level when the shot is initiated.

Some licensees use a silicone rubber seal on the parting line surface of the tool block to prevent air leakage. Others do not use the rubber seal but accept the parting line leakage and overcome it with greater vacuum pump capacity.

Trim dies are used to remove the molded components from the gating system cleanly. In addition, they can be constructed to remove any flash on internal and external features at the time of gate removal. High-production jobs usually utilize trim dies for removal consistency. Cutting surfaces for trim tools are typically made from A-2 steel while the bodies can be made of any good quality steel such as 4140.

Licensed Thixomolding machine builders are JSW, Hiroshima, Japan, and Husky ThixoSystems, Bolton, Onario, Canada. Current machine sizes range from 75 to 1,600 metric tons clamp capacity. Thixomolding is a registered trademark of Thixomat Inc., Ann Arbor, MI,

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Thixomolding:

Plastic Injection Molding Turns to Metal

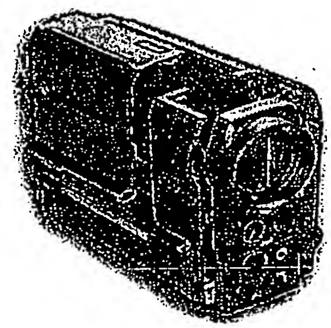
The Thixomolding process offers magnesium castings with high strength and low wall thickness for the consumer electronics and automotive industries.

Stephen LeBeau, *Thixomat, Inc.*
Joseph Maffia, *Assistant Editor*

In a consumer electronics world seemingly dominated by injection molded plastic, thin-walled magnesium components produced by thixomolding provide an alternative option. The thixomolding process combines elements of conventional diecasting and plastic injection molding into a one-step process for the net shape molding of magnesium alloys to produce parts for consumer electronics products such as personal computers, portable CD players and digital cameras.

Castings for the electronics industry require certain thermal and electrical properties, high strength and thin walls. The two-part solution for these specifications is the use of magnesium alloys, which possess excellent thermal properties, inherent electromagnetic interference shielding and a low density, and the thixomolding process.

Thixomolding is also used for several automotive components, including transmission parts and covers, because of magnesium's ability to add functional space while the casting weight is reduced.



The Sharp VL-PD1 video camera features a thixomolded magnesium thin wall (<1.0 mm) external case.

The process is as follows:

1. Magnesium alloy feedstock is introduced by a volumetric feeder in the form of metal granules at room temperature to the heated barrel and screw.
2. The material is thermal-mechanically processed by the rotating screw, transferred to the accumulation zone and then injected into a die cavity.
3. The temperature of the material is raised to a semi-solid region. The energy necessary to bring the metal to its semi-solid temperature is provided by resistance band heaters.
4. The temperature profile selected for the barrel depends on the alloy being processed. When processing the AZ91D magnesium alloy, the nominal slurry injection temperature is 1075F (580 C).
5. An argon atmosphere is maintained in the barrel during operation to minimize oxidation of the magnesium alloy.
6. The shot size (the distance that the reciprocating screw retracts during a shot cycle) is determined primarily from the weight of the part being produced, and to a lesser degree, the retract rate and the rotational speed of the screw. These interactive processing variables are balanced with the volumetric feeder supplying the magnesium alloy to the thixomolder.
7. The semi-solid slurry is injected into a preheated metal mold. The screw is driven forward hydraulically at the desired velocity, filling the die cavity. The

The Process

Figure 1 illustrates a thixomolding system. The process produces near net shape castings with no investment in molten metal processing and handling equipment and also eliminates the safety hazards of handling molten magnesium.

The injection system, which is similar to plastic injection molding machines, consists of a high temperature screw and barrel. These components are coupled to a high speed shot system, which drives the reciprocating screw.

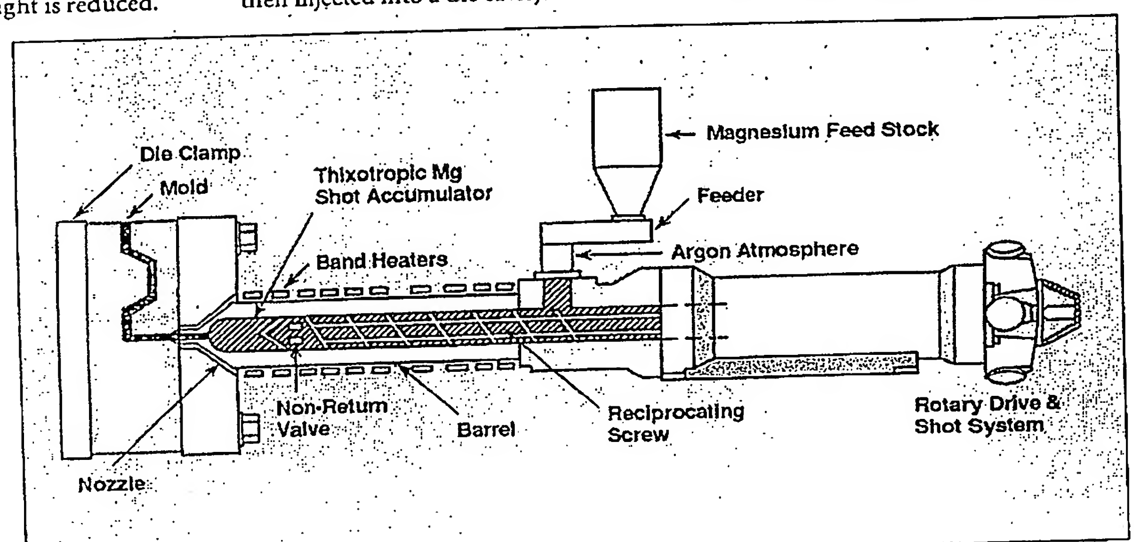


Fig. 1. Pictured is a schematic of a thixomolder, which combines diecasting and plastic injection molding.

Table 1: Typical Mechanical & Physical Properties of Thixomolded Alloys

	AZ-91-D	AM-50A	AM-60B	AE-42	ZA-8
Mechanical Properties					
Ultimate Tensile Strength (Ksi)	34	32	32	33	54
Yield Strength (Ksi)	23	18	19	20	42
Compressive Yield Strength (Ksi)	24	NA	19	NA	37
Elongation (%)	6	13	9	9	8
Hardness (BHN)	75	57	62	57	106
Shear Strength (Ksi)	20	NA	NA	NA	40
Impact Strength (Btu/lb)	1.6	7.0	4.5	4.3	35
Fatigue Strength (Psi x 10^6)	10	10	10	NA	15
Physical Properties					
Density (lb/in3)	0.666	0.064	0.065	0.064	0.227
Melting Range (°C)	470-595	543-620	540-615	565-620	375-404
Specific Heat (BTU/lb°F)	0.25	0.25	0.25	0.24	0.104
Thermal Conductivity (BTU/ft hr °F)	41.8	36	36	40	66.3
Poisson's Ratio	0.35	0.35	0.35	0.35	0.30

rotating screw then retracts, filling the accumulation chamber in preparation for the next shot. Shot velocities are used in excess of 250 cm/s with metal pressures ranging from 31-55 MPa.

Advantages of Thixomolding

Thixomolded components are viewed as alternatives to plastic injection molded and diecast parts. The advantages provided by thixomolded castings over other components are:

Reduced Porosity—The small amount of turbulence and low molding temperatures allows thixomolding to produce castings with low levels of porosity, which also eliminates the cost of puttying and surface coatings. The metal fills the mold in a plane flow front, producing fine details in molded parts with high-quality surface finish. The lower porosity levels also allow the parts to be heat treated to improve mechanical properties.

Dimensional Stability—The dimensional stability of the process enables the manufacturer to mold locating pins, holes and other features with precision and repeatability and without requiring additional machining. Many optical devices such as digital cameras require dimensional stability unachievable by other manufacturing processes.

Near-Net-Shape Components—The process produces near-net-shape castings, eliminating large draft requirements to permit efficient part design and reduced machining. While 3% draft is recommended for sidewalls and cored holes, lower draft is possible in many parts, with zero draft possible for selected applications on a limited basis.

Environmentally Friendly Process—Thixomolding does not require any external foundry or material handling—the process is contained within the molding machine. By keeping the magnesium enclosed, environmentally friendly argon can be used to prevent oxidation. Also, since no flux is used in the process, any scrap material is clean and recyclable. No secondary cleaning steps are required.

Designing for Thixomolding

Converting a component to magnesium for thixomolding requires a complete analysis that includes using design capabilities to make cost-effective magnesium conversions a reality. The thixomolding process is not a substitute process in which existing de-

Origins of the Thixomolding Process

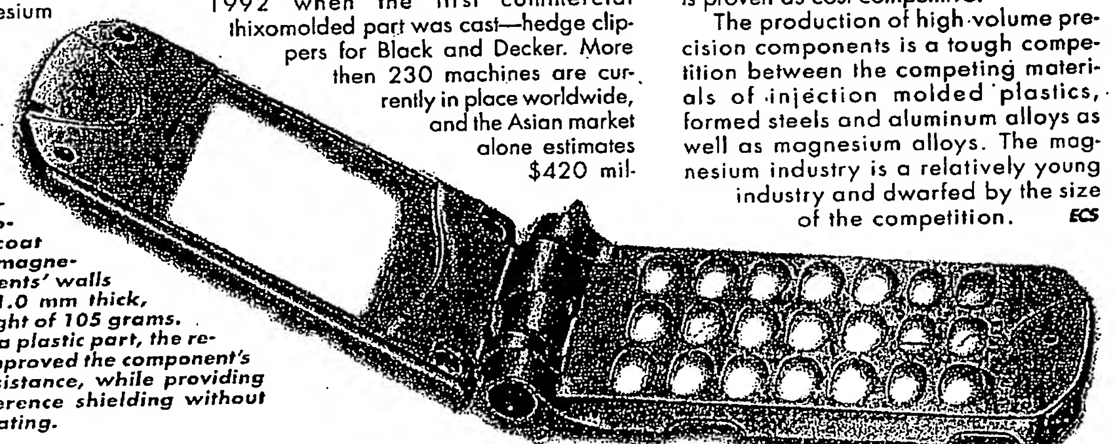
The thixomolding process combines elements of both conventional diecasting and plastic injection molding into a one-step process for the net shape molding of magnesium-based alloys. Thixomolding is already used to make over 5 million parts/yr, and as much as 25% of mobile phone production is projected to demand magnesium structural components.

Dow Chemical Co. , Midland, Michigan, first developed the process, which calls for the injection molding of metal, in the 1980s. The process concept was based on earlier research conducted at MIT. The metal (magnesium, zinc or aluminum) is heated to a semi-solid state and then formed into a machine similar to a plastic injection molding machine.

The process was commercialized in 1992 when the first commercial thixomolded part was cast—hedge clippers for Black and Decker. More then 230 machines are currently in place worldwide, and the Asian market alone estimates $420 million in parts production.

Today, the process is used in consumer electronics and, to a lesser degree, the automotive industry. The current automobile contains approximately 7 lbs of magnesium castings. That is expected to grow to approximately 50 to 100 lb/automobile by 2019, assuming that magnesium is proven as cost competitive.

The production of high-volume precision components is a tough competition between the competing materials of injection molded plastics, formed steels and aluminum alloys as well as magnesium alloys. The magnesium industry is a relatively young industry and dwarfed by the size of the competition. **ECS**



This cellular phone keypad and display enclosure was cast by Colcoat Co., Ltd., using AZ-91D magnesium alloy. The components' walls are between 0.8 and 1.0 mm thick, with a total casting weight of 105 grams. Previously designed as a plastic part, the redesign to magnesium improved the component's rigidity and impact resistance, while providing electromagnetic interference shielding without external coatings or plating.

signs in plastic can be implemented.

The maximum return on a firm's investment is achieved when the process initially is chosen as the production method. This is especially true when the engineered component has variances in wall thickness or where the possibility exists to eliminate extraneous subcomponents through creative design engineering.

By initiating thixomolding at the design stage, manufacturers are able to define a configuration that best takes advantage of the net-shape capability and the properties of the magnesium alloy being used. It also will be easier to maintain laminar flow of the semi-solid metal through the gating system, utilize tight tolerance control and aim to eliminate costly secondary machining.

Most thixomolded parts must meet specified structural requirements in the application for which they are intended. When designing to replace an aluminum part, additional stiffness can be added by adding ribs or by adding to the thickness of the critical section. The stiffness-to-weight ratio of magnesium castings is greater than that of engineered plastics and aluminum die castings.

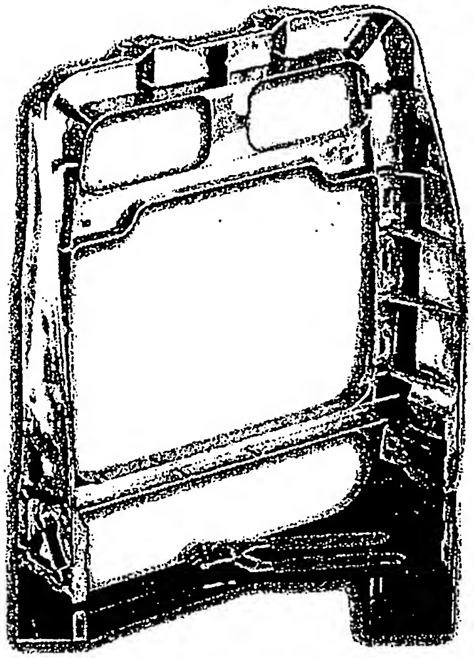
The typical mechanical properties of thixomolded magnesium alloys are given in Table 1. These can be used in the design process when yield strength, fatigue strength or creep performance are the controlling criteria.

Applications

Thixomolding has gained popularity in the production of consumer electronics (personal computers, portable CD players, digital cameras; cell phones, video cameras, liquid crystal display projectors and calculators) and the automotive industry. Following are examples of both industries that use thixomolding.

Consumer Electronics—Thixomolded castings are used on a variety of consumer electronics. They can be found as the body of mini-disk players and digital video cameras, the housing of digital cameras, the enclosure of digital LCD projectors, and the LCD frame and keyboard of cell phones.

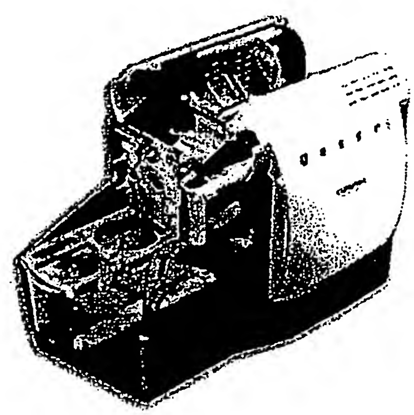
The ability to mold complex, net shape parts allows thixomolding to take full advantage of the electromagnetic interference (EMI) shielding and thermal properties of magnesium. In any electronic device, EMI can affect performance when unwanted electromagnetic energy creates a disturbance within the receiving device. In order to minimize these effects, it is necessary to provide a conductive barrier. A thin-walled magnesium frame is a simple and effective solution. Thixomolded alloys are now replacing engineered plastics in many parts of the electronics industry.



By converting to thixomolding, this automotive seat frame component reduced total seat assembly from 15 welded steel parts to 5 thixomolded parts and resulted in a 40% weight reduction.

Metal castings also contain a number of aesthetic advantages over plastics. The look and feel of metal is perceived by customers as high quality, and it has great wear resistance. It is 30 times stiffer than plastic and allows much thinner housings (nominally 1.0–1.2 for PC notebook covers and even thinner (0.6 mm) for smaller consumer devices such as mobile phones or mini-disk players).

Various Consumer Products—The features of net-shape and precision tolerances are being adapted in a variety of consumer products in North America. Power hand tools (reciprocating saws, hand drills, cordless hammer drills and pneumatic nailers) are using gear case covers and housings produced via thixomolding. Recently, the applications have expanded into the sports equipment arena where high performance and lightweight are key for new products (K-2 snowboard boot binder, fishing reels and sport fashion sunglass frames are all featuring magnesium components). The Buell division of Harley Davidson recently introduced their new high performance Firebolt XB9R motorcycle sporting a thixomolded magnesium console.



Shown is an exploded view of a Compaq digital projector with three internal parts and three external thixomolded parts. Critical features were lightweight, precision tolerances and the ability to dissipate heat.

Automotive Industry—The automotive industry is actively increasing the use of magnesium alloy components to take full advantage of magnesium being the lightest structural material.

Thixomolded transmission parts and covers are being evaluated by manufacturers utilizing new high temperature magnesium alloys developed by the primary magnesium suppliers as they strive to improve the fuel efficiency of automobiles. Numerous other components, including seat backs, glove boxes and extension housings, are expected to be in production over the next few years.

Thixomolding technology can contribute to the way vehicles will be built in the future; including offering the possibility to add functional space while weight is reduced. The European market is leading both the North American and Asian markets in developing an approach to improved magnesium product design. ECS

About the Author

Stephen LeBeau is the vice president of sales and marketing at Thixomat, Inc., Ann Arbor, Michigan. LeBeau, who holds degrees in metallurgical and materials engineering from Michigan Technological Univ., Rensselaer Polytechnic Institute and the Univ. of Wisconsin—Madison, previously worked for USX Steel, Caterpillar Tractor, Babcock & Wilcox and Peerless Metal Powders. He is a member of ASM, TMS-AIME, SME, NADCA and SAE.

For More Information

"A Product Designer's Guide to Thixomolding of Magnesium Alloy Parts," Engineered Casting Solutions, Fall 2002, Website Only Article at www.castsolutions.com.

"Thixomolding Promises Savings," T. Bex, MODERN CASTING, August 1992, p.24.